NEW CHALLENGES IN POTATO BREEDING TO COPE WITH CLIMATE CHANGE: DUAL TOLERANCE TO HEAT AND DROUGHT

Mehmet Emin ÇALIŞKAN[1]

e-mail: caliskanme@nigde.edu.tr

Abstract

Potato is a cool season crop with an optimal growth temperature between 17 and 21ºC, and it also very sensitive to drought stress. All climate scenarios indicate that the global climate is changing and will continue to change in the near future. The main challenges from climate change to agriculture and food production are the more frequent and severe drought and floods as well as adverse effects of high growth temperatures. The total global yield in the regions currently cropped with potato was calculated to decline up to 32% without adaptation to climate change. The breeding of heat and drought tolerant potato cultivars is one of the most feasible and practical approaches to cope with global warming. However, breeders are generally focused on development of heat or drought tolerant potato cultivars instead of dual tolerance to both stresses. Previous studies indicate that tolerance mechanism for heat and drought is different in potato. Screening of many breeding lines against heat and drought stress under field conditions during early generations is not feasible for many breeding programs due to high cost and labor requirements. Therefore, rapid and reliable screening methods are needed to evaluate large populations in early generations. Biotechnological tools offer some advantages to breeders for screening large populations especially against biological stress factors, but no sound achievements obtained for abiotic stress factors in potato up to now. Currently our research group has several projects to develop novel screening tools to identify heat and drought tolerant genotypes.

Key words: *Solanum tuberosum* L., abiotic stress, water stress, temperature, phenotyping

The potato (*Solanum tuberosum* L.) is a world crop growing in around 160 countries from sea level to 4000 m altitude and between the 50° S and 40° N latitudes. It is the fourth most produced food crop, and the first non-cereal crop in the world with an annual production of 385 x 10^6 t (Anonymous, 2016).

Although it has a wide adaptation area, potato is a very sensitive to environmental stresses such as drought, heat, and salinity (Kikuchi *et al*, 2015). The majority of the annual world potato production is contributed by developing countries, where it is cultivated in marginal areas prone to environmental anomalies. Therefore, development of tolerant potato cultivar to harsh environmental conditions is very important for sustainable food production in less developed countries. In addition, sustainability of potato production has also been threatening by the global climate change in the most of traditional production regions in temperate zones.

All climate scenarios indicated that global climatic patterns are being greatly altered due to increasing atmospheric CO_2 concentrations. The Intergovernmental Panel on Climate Change (IPCC) reports that global mean temperatures increased 0.045ºCper decade during the last 150 years while it has increased almost four times more (0.177°C) during last three decades (Anonymous, 2007). It is expected that the global temperature will increase 1.1-6.4ºCdepending on regions until end of this century (Anonymous, 2007). The increases in temperature are associated with extreme variations in weather patterns, resulting in fluctuations in rainfall regimes (severe droughts or heavy rains), and/or atypically heat waves (Rötter, van de Geijn, 1999). Therefore, breeders have to consider effects of multiple stress factors when they aimed to develop crop cultivars adapted to climate change.

In this paper, it was discussed the effects heat and drought stress on potato crops, and breeding strategies to develop climate resilient potato cultivars.

EFFECTS OF DROUGHT STRESS

Actually, water use efficiency of potato is higher than many other important food crops such as wheat, maize, rice, etc. Potato produces 5600

[1] Nigde University, Faculty of Agricultural Sciences and Technologies Nigde, Turkey

kcal dietary energy with per m^3 of water applied while maize, wheat and rice produces only 3860, 2300 and 2000 kcal using same amount of water, respectively (Renault, Wallender, 2000). However, potato is more sensitive to water deficiency due to shallow root system (Iwama, 2008). Drought stress negatively affects plant growth, tuber yield and quality in different magnitude depending on the timing, duration and severity of the stress (Monneveux *et al,* 2013). Tuber initiation and bulking stages are the most sensitive stages to water deficiency, and both number and size of tubers significantly reduces due to inadequate water supply during these stages (MacKerron, Jefferies, 1986). Transient drought during tuber bulking also lead to secondary growth (dumbbell-shaped, knobby, or pointed-end tubers) (MacKerron, Jefferies, 1986). Growth, yield and quality responses of potato cultivars to drought stress significantly differ (MacKerron, Jefferies, 1986; Cabello *et al,* 2012; Stark *et al,* 2013; Banik *et al,* 2016).

Potato is grown as rainfed crop without irrigation in some countries in temperate regions while irrigation is essential in the most countries especially in sub-tropical and tropical regions. A fluctuation in rainfall regime or transient drought periods due to climate change significantly threats the potato production in rainfed production regions. On the other side, potatoes are irrigated up to twenty times using 700-900 mm water in some countries, i.e. Turkey. This results in depletion of ground water level and increase in production cost. Hence improving water use efficiency of potato cultivars is very crucial for sustainability of potato production in both types of environments.

EFFECTS OF HEAT STRESS

The potato is a cool season crop with an optimal growth temperature between 17 and 21ºC (Levy, Veilleux, 2007). The higher temperatures than the optimum significantly affect several physiological processes related with yield and quality such as haulm growth, dry matter production and partitioning, tuber initiation and growth, photosynthetic rate, synthesis of hormones, enzymes and other metabolites (Levy, Veilleux, 2007). Supra-optimal temperatures significantly reduce canopy leaf area index, canopy photosynthesis (Fleisher *et al*, 2006; Timlin *et al*, 2006), tuber initiation and tuber growth (Struik *et al*, 1989; van Dam *et al*, 1996), and internal and external quality of tubers (Sterret *et al*, 1991; Lafta and Lorenzen, 1995; Rykaczewska 2015).

It is expected that the global temperature will increase 1.1-6.4ºCdepending on regions until end of this century (Anonymous, 2007). Hijmans (2003) estimated the effects of global warming on potato production in different regions of the world using different projections. He concluded that potential yield of potato could decrease around 18-32% in general, but decline can be higher in some regions (i.e. 36.7% in Turkey) if any precautions are not taken. Hijmans (2003) suggested that the detrimental effects of global warming could be reduced by shifting planting dates and development of heat tolerant cultivars. Apart from the global warming, breeding heat tolerant potato cultivars is also very important to get high yield in tropical, sub-tropical and Mediterranean-type environments due to supra-optimal temperatures during growing period.

BREEDING STRATEGIES FOR CLIMATE RESILIENT CULTIVARS

The threat of climate change and aforementioned effects of drought and heat stress on potatoes confronts potato breeders with enormous challenges to generate climate resilient cultivars. Actually, climate change will also bring other problems such as salinity, frost, epidemics of new diseases and pests. However, breeders generally focus on improve only one of threats such as drought, heat, salinity, or a single disease. The focus on improving potato characteristics to tolerate drought and heat has generally been overlooked (Monneveux *et al*, 2013). Especially dual tolerance to heat and drought stresses will be very important since plants will generally face with both stresses simultaneously with changing climate in future (Peverelli and Rogers, 2013; Kole *et al,* 2015; Mazdiyasni and AghaKouchak, 2015). Where heat and drought stress occur simultaneously, they generally result in more extreme detrimental effects than would each stress separately (Peverelli and Rogers, 2013; Lipiec *et al,* 2013). Moreover, their joint presence can also alter plant metabolism in novel ways compared to each applied individually (Rizhsky *et al,* 2004). The severity of decline in tuber quality and yield increases when heat stress accompanies drought stress in potato (Ahn *et al,* 2004, Aksoy *et al,* 2015). Yield losses combined with low crop quality could drastically impact the economic output and the overall human food supply.

There are two prerequisites for success of a traditional breeding program aims to development of heat and drought tolerant cultivar: choosing the most appropriate parents, and using of the reliable screening methods in early generations (Hijmans, 2003; Levy, Veilleux, 2007). Previous studies indicated that it is possible to find sources for heat

(Gautney and Haynes, 1983; Levy, 1986; Levy *et al*, 1991; Reynolds and Ewing, 1989; Midmore and Prange, 1991) and drought tolerance (Coleman 2008; Cabello *et al,* 2012; Schafleitner *et al,* 2007; Sprenger *et al,* 2015) amongst potato cultivars, breeding lines, and wild *Solanum* species.

However direct selection for drought and heat tolerance by assessing performance and yield is very complex and time-consuming, as it requires trials on managed field sites either in areas with frequent droughts or under expensive rain-out shelters. In the most cases, it can be not possible to create a selection environment having both stresses simultaneously. As both drought and heat tolerances are multigenic traits, the combinations of favorable alleles that achieve high tolerances are very rare events. Thus, understanding the tolerance mechanism and novel screening techniques are needed to identify genotypes having dual-tolerance to both stresses. Recent developments in molecular biology and genetics offer new tools to breeders to develop more tolerant potato cultivars.

Phenomics and genomics are two important and trendy tools in developing stress tolerant cultivars. A high-throughput phenotyping is a key step to identify individuals tolerant to targeted stress factors (Ghanem *et al,* 2015). Screening of individuals for morphological (i.e. number and size of leaves, plant height, root size, etc.), physiological (i.e. chlorophyll content, carbon exchange rate, transpiration rate), and biochemical (i.e. stress enzymes, plant hormones) traits can give very useful information to define and ideotype under stressful condition (Ghanem *et al,* 2015). In recent years, imaging and monitoring systems have been used as a high-throughput phenotyping platform especially against stress factors (Araus. Cairns, 2014). These platforms generally use sensors, robotics, aeronautics, and high-performance computing tools, but more practical and low-cost approaches are also needed (Araus, Cairns, 2015; Ghanem *et al*, 2015).

In a broad term, genomics tools offer knowledge and information about single genes, pathways or gene networks, and genome structure and behavior (Langridge and Reynolds, 2015). Application of DNA markers to identify genotypes having desired traits have successfully implemented to breeding scheme of many crop species. Markers can provide a framework to identify genomic regions (e.g. quantitative trait loci, QTLs) that influence traits of interest (Ghanem *et al,* 2015). Unfortunately, a limited number of QTLs for complex traits of drought and/or heat tolerance have been detected by traditional QTL mapping approach while no validated selection markers have been developed for selection heat and/or drought tolerant potato genotypes. Recently several projects are ongoing to identify selection markers using Genome-wide Association Study (GWAS) approach. The Next Generation Sequencing technology along with phenotyping data are used for GWAS approach. Khan *et al* (2015) newly reported 45 QTLs related with drought tolerance in potato using GWAS approach. The main advantages of GWAS include: 1) no need to make crosses to generate segregating populations; 2) a collection of various cultivars and breeding lines can be utilized for mapping studies; 3) higher mapping resolution may be reached with many more meiotic recombination events (Aksoy *et al*, 2015). However, this approach also needs also collection of accurate phenotypic data to match traits and genes related to tolerance. Transcriptomics, miRNAs and trangenics can offer also useful tools to study on heat and drought tolerance in crops (Aksoy *et al*, 2015).

CONCLUSIONS

It is obvious that global warming threats the sustainability of potato production in most regions throughout the world. Therefore, potato breeders should consider to develop tolerant cultivars to adapt upcoming changing environment. However, many recent potato breeding programs erroneously focused on only drought or heat tolerance instead of dual tolerance to both stresses whereas plants will generally face with both stresses simultaneously with changing climate. Hence we strongly suggest to include both stress factors in new breeding programs. Inclusion of phenomics and genomics tools to breeding program is also essential to accelerate breeding process of climate resilient potato cultivars.

REFERENCES

Ahn Y., Claussen K., Zimmerman J.L., 2004 - *Genotypic differences in the heat-shock response and thermotolerance in four potato cultivars.* Plant Science, 166: 901-911.

Aksoy E., Demirel U., Öztürk Z.N., Çalışkan S., Çalışkan M.E., 2015 - *Recent advances in potato genomics, transcriptomics, and transgenics under drought and heat stresses: a review.* Turkish Journal of Botany, 39:920-940.

Anonymous, 2007 - *Climate change 2007: impacts, adaptation and vulnerability*, in Contribution of Working Group II to the 4th Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge, UK).

Araus J.L., Cairns J.E., 2014 - *Field high-throughput phenotyping: the new crop breeding frontiers.* Trends in Plant Science, 19: 52-61.

Banik P., Zeng W., Tai H., Bizimungu B., Tanino K., 2016 - *Effects of drought acclimation on drought stress resistance in potato (Solanum tuberosum*

L.) genotypes. Environmental and Experimental Botany, 126: 76-89.

Cabello R., De Mendiburu F., Bonierbale M., Monneveux P., Roca W., Chujoy E., 2012 - *Large-Scale Evaluation of Potato Improved Varieties, Genetic Stocks and Landraces for Drought Tolerance.* American Journal of Potato Research, 89: 400-410.

Coleman W.K., 2008 - *Evaluation of wild Solanum species for drought resistance 1. Solanum gandarillasii Cardenas.* Environmental and Experimental Botany, 62: 221-230.

Fleisher D.H., Timlin D.J., Reddy V.R., 2006 - *Temperature influence on potato leaf and branch distribution and on canopy photosynthetic rate.* Agronomy Journal, 98: 1442-1452

Gautney T.L., Haynes F.L., 1983. *Recurrent selection for heat tolerance in diploid potatoes (Solanum tuberosum subsp. phureja and stenotomum).* American Potato Journal, 60: 537-542.

Ghanem M.E., Marrou H., Sinclair T.R., 2015 - *Physiological phenotyping of plants for crop improvement.* Trends in Plant Science, 20: 139-144.

Hijmans R.J., 2003 - *The effect of climate change on global potato production.* American Journal of Potato Research, 80: 271-280.

Iwama K., 2008 - *Physiology of the potato: new insights into root system and repercussions for crop management.* Potato Research, 51:333–353**.**

Khan M.A., Saravia D., Munive S., Lozano F., Farfan E., Eyzaguirre R., Bonierbale, M., 2015 - *Multiple QTLs linked to agro-morphological and physiological traits related to drought tolerance in potato.* Plant Molecular Biology Reporter, 33:1286-1298.

Kikuchi A., Huynh H.D., Endo T., Watanabe K., 2015 - *Review of recent transgenic studies on abiotic stress tolerance and future molecular breeding in potato*. Breeding Science, 65: 85.

Kole C., Muthamilarasan M., Henry R., Edwards D., et al,, 2015 - *Application of genomics-assisted breeding for generation of climate resilient crops: progress and prospects.* Frontiers in Plant Science, doi: 10.3389/fpls.2015.00563

Lafta A.M., Lorenzen J.H., 1995 - *Effect of high temperature on plant growth and carbohydrate metabolism in potato.* Plant Physiology, 109: 637-643.

Langridge P., Reynolds M.P., 2015 - *Genomic tools to assist breeding for drought tolerance.* Current Opinion in Biotechnology, 32: 130-135.

Levy D., 1986 - *Genotypic variation in the response of potatoes (Solanum tuberosum L.) to high ambient temperaturs and water deficit.* Field Crops Research, 15: 85-96.

Levy D., Coleman W.K., Veilleux R.E., 2013 - *Adaptation of potato to water shortage: Irrigation management and enhancement of tolerance to drought and salinity.* American Journal of Potato Research, 90: 186-206.

Levy D., Veilleux R. E., 2007 - *Adaptation of potato to high temperatures and salinity—A review*. American Journal of Potato Research, 84: 487–506.

Lipiec J., Doussan C., Nosalewicz A., Kondracka K., 2013 - *Effect of drought and heat stresses on plant growth and yield: a review*. International Agrophysics, 27: 463– 477.

MacKerron D.K.L., Jefferies R.A., 1986 - *The influence of early soil moisture stress on tuber numbers in potato*. Potato Research, 29: 299–312.

Mazdiyasni O., AghaKouchak A., 2015 - *Substantial increase in concurrent drought and heatwaves in the United States.* PNAS, 112: 11484-11489.

Midmore D.J., Prange R.K., 1991 - *Sources of heat tolerance amongst potato cultivars, breeding lines and Solanum species.* Euphytica 55: 235-245.

Monneveux P., Ramirez D.A., Pino M., 2013 - *Drought tolerance in potato (S. tuberosum L.). Can we learn from drought tolerance research in cereals?* Plant Science, 205-206: 76-86.

Peverelli M.C., Rogers W.J., 2013 - *Heat stresseffects on crop performance and tools for tolerance breeding.* Rev. FCA UNCUYO, 45: 349-368.

Reynolds M., Ewing E.E., 1989 - *Heat tolerance in tuber bearing Solanum species: A protocol for screening.* American Potato Journal, 66: 63-74.

Rizhsky, L.; Liang, H.; Shuman, J.; 2004 - *When defense pathways collide. The response of Arabidopsis to a combination of drought and heat stress.* Plant Physiology, 134: 1683-1696.

Rötter R., van de Geijn S.C., 1999 - *Climate change effects on plant growth, crop yield and livestock*. Climate Change, 43: 651-681.

Rykaczewska K., 2015 - *The effect of high temperature occurring in subsequent stages of plant development on potato yield and tuber physiological defects*. American Journal of Potato Research, 92: 339-349.

Schafleitner R., Gutierrez R., Espino R., Gaudin A., Pérez J., Martínez M., Domínguez A., Tincopa L., Alvarado C., Numberto G., Bonierbale M., 2007 *Field screening for variation of drought tolerance in Solanum tuberosum L. by agronomical, physiological and genetic analysis.* Potato Research 50, 71–85.

Sprenger H., Rudack K., Schudoma C., Neumann A., Seddig S., Peters R., Zuther E., Kopka J., Hincha D.K., Walther D., Köhl K., 2015 - *Assesment od drought tolerance and its potential yield penalty in potato.* Functional Plant Biology, 42: 655-667.

Stark J.C., Love S.L., King B.A., Marshall J.M., Bohl W.H., Salaiz T., 2013 - *Potato cultivar response to seasonal drought patterns.* American Journal of Potato Research, 90: 207–216.

Sterret S.B., Henninger M.R.., Lee G.S., 1991 - *relationship of internal heat necrosis of potato to time and temperature after planting.* Journal of American Society of Horticultural Sciences, 116: 697-700.

Struik P.C., Geertsema J., Custers C.H.M.G., 1989 - *Effect of shoot, root and stolon temperature on the development of the potato (Solanum tuberosum L.) plant. I. Development of tubers.* Potato Research, 32: 151-158.

Timlin D., Rahman S.M.L., Baker J., Reddy V.R., Fleisher D., Quebedeaux B., 2006 - *Whole plant photosynthesis, development, and carbon partitioning in potato as a function of temperature*. Agronomy Journal, 98: 1195-1203.

van Dam J., Kooman P.L., Struik P.C., 1996 - *Effects of temperature and photoperiod on early growth and final number of tubers in potato (Solanum tuberosum L.).* Potato Research, 39: 51-62.